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Combustion and Emission Characteristics of Multiple Premixed Compression Ignition (MPCI) Mode with Low Octane Gasoline Fuels

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Abstract

This paper studies the combustion and emission characteristics of three kinds of low octane fuels which are naphtha, the blend of gasoline and diesel (G70D30), the blend of gasoline and n-heptane (G70H30) in multiple premixed compression ignition (MPCI) mode. Commercial diesel is also tested in conventional diesel combustion mode as a reference. The study is carried out in a single cylinder diesel engine with a compression ratio of 16.7. By varying the common rail pressure, the effect of injection pressure on combustion and emissions is investigated.

The results illustrate that the combustion delay of the gasoline-type fuels is extended with the increase of injection pressure. The soot emission decreases at high injection pressure with a penalty of higher CO and HC emissions. Increasing the injection pressure also reduces the particle number in accumulation mode, but produces more in nucleation mode. Among the test fuels, naphtha has the lowest NO_x emission due to low combustion temperature but the highest CO and HC emissions. There is no significant difference in particle size distribution for the three fuels. The indicated thermal efficiency of gasoline-type fuels increases with the rise of injection pressure and it is higher than that of diesel at high injection pressure.

The diesel fuel has lower CO and HC emissions than the gasoline-type fuels, but much higher pressure rise rate, NO_x and soot emissions due to high combustion temperature and poor premixing. Therefore, the low octane gasoline fuels are more suitable than the diesel for the compression ignition engines in terms of the emissions.

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Keywords: low octane gasoline; multiple premixed compression ignition (MPCI); emissions

1. Introduction

As a new and clean combustion mode, gasoline compression ignition is widely studied in recent years.

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Because of its high volatility and long ignition delay, the gasoline-type fuel can form pre-mixture more easily than diesel to realize high efficiency and low emission combustion [1]. Compared with the traditional gasoline with high octane number, the low octane gasoline has higher auto-ignition ability and is more suitable for gasoline compression ignition mode [2,3,4]. Besides, the low octane gasoline like naphtha is produced much simpler with less cost compared to the high octane gasoline. This paper studies the combustion and emission characteristics of the low octane gasoline fuels in multiple premixed compression ignition (MPCI) mode and compares with the diesel under single and double injection conditions.

2. Test fuels and methods

The test fuels are the blend of gasoline and diesel (G70D30), the blend of gasoline and n-heptane (G70H30), and heavy naphtha. Both the blending ratios for G70D30 (gasoline: diesel) and G70H30 (gasoline: n-heptane) are 70:30 by volume. According to the calculation by empirical formulas, these fuels have the same level of research octane numbers (RON). The commercial diesel is also tested to compare with the low octane gasoline fuels, and the diesel with single injection is marked as the baseline. Table 1 lists the properties of gasoline, diesel, n-heptane and heavy naphtha fuels.

Table 1. Test fuel properties

properties	gasoline	diesel	n-heptane	heavy naphtha
RON	92	-	0	65.6
CN	-	52.6	-	-
density(kg/m3 @ 20°C)	746.9	839.3	632	747.1
LHV(MJ/kg)	42.95	42.9	44.6	43.67
aromatics(V%)	35.6	29.6	0	5.9
T10(°C)	48.8	214.8	-	97.4
T50(°C)	95.5	266.1	-	115.4
T90(°C)	168.9	333.6	-	141.9

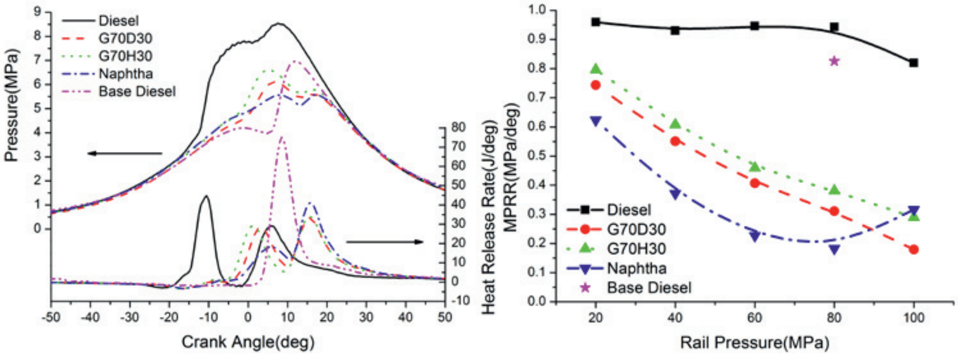
The test engine is a single-cylinder compression ignition engine modified from a four-cylinder diesel engine [4]. In the test, the injection pressure varies by adjusting the rail pressure from 20MPa to 100MPa. The engine speed is 1600rpm and the IMEP is 0.7MPa. The intake pressure and temperature are the ambient pressure and temperature.

3. Results and discussions

3.1. Combustion characteristics

For gasoline-type fuels, the ignition becomes late and the first peak of the heat release rate decreases while the second one increases when injection pressure increases. However, increasing injection pressure results in earlier ignition for diesel fuel. The diesel is easier to form equivalent fuel-air mixture when the injection pressure is increased due to its lower volatility. While the local fuel-air mixture of gasoline and naphtha is too lean with high injection pressure due to better fuel atomization.

Fig. 1 shows the cylinder pressure, heat release rate at 80MPa of rail pressure and maximum pressure rise rate (MPRR). It can be seen that among low octane gasoline fuels, G70H30 combustion initiated the earliest due to the high auto-ignition of n-heptane in the mixture. The initiation of heavy naphtha combustion is the latest. The first peak in the heat release rate of G70D30 is similar to that of G70H30, whereas it is lower for naphtha because of its later ignition. Diesel combustion has a significant part of heat release from diffusion combustion both with single and double injections. Diesel MPRR (maximum pressure rise rate) is much higher and less sensitive to injection pressures than gasoline fuels.

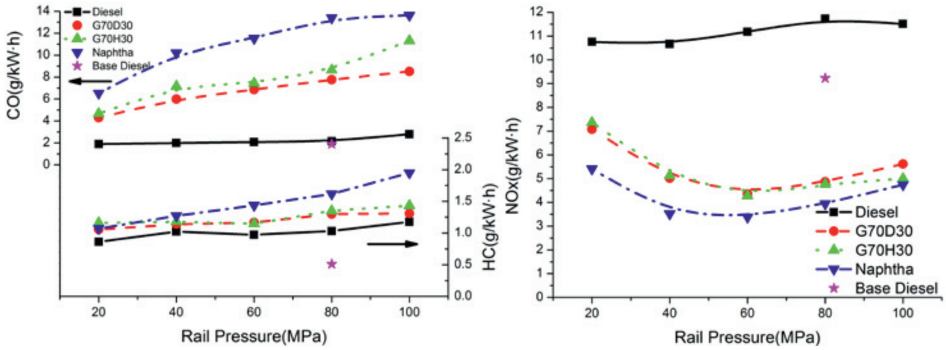


(a) (b)

Fig. 1. (a) cylinder pressure and heat release rate; (b) MPRR of different fuels

3.2. Gas emission characteristics

For gasoline-type fuels, the emissions of CO and HC are higher than those of diesel and increase with the rise of the injection pressure in Fig. 2(a). As discussed in 3.1, a high injection pressure results in lean fuel-air mixture, which is difficult to be ignited with incomplete combustion of more fuel near the cylinder wall. Additionally, high injection pressure can increase the penetration length, which may cause more serious wall impingement and quenching. With better volatility and longer combustion delay, naphtha produces more CO and HC emissions than other two kinds of gasoline-type fuels due to more incomplete combustion and quenching. The emission of NO_x from gasoline-type fuels is much lower than that from diesel as shown in Fig. 2(b). NO_x emission of gasoline-type fuels is also sensitive to the injection pressure. Low or high injection pressure produces more NO_x emission due to high local temperature from first or second stage heat release respectively. Compared with other fuels, heavy naphtha has the lowest NO_x emission.



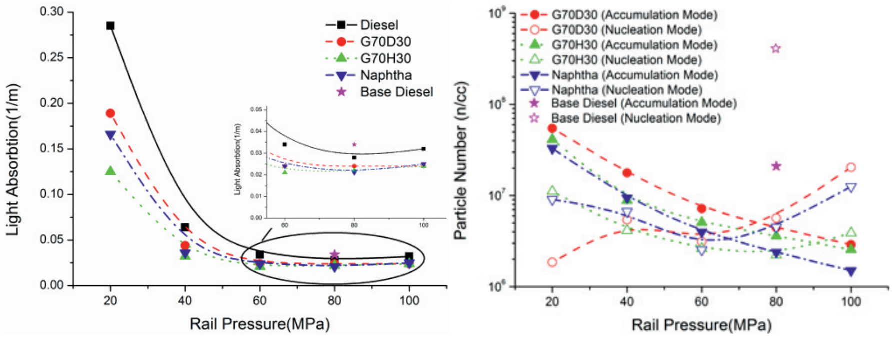
(a) (b)

Fig. 2. (a) CO and HC emissions; (b) NO_x emission

3.3. PM emission characteristics

The soot emission decreases dramatically with the rise of injection pressure as shown in Fig. 3(a). When the rail pressure is low from 20MPa to 40MPa, the fuels have poor atomization leading to a lot of rich mixture gas and then high soot formation, especially in the second injection. The diesel fuel has more soot emission than gasoline-type fuels because of its poorer premixing. The gasoline-type fuels show the same level of soot emission.

Fig. 3(b) shows the particle number of three kinds of gasoline-type fuels under different injection pressures. With the increase of injection pressure, the total particle number shows the declining trend. The particle number decreases dramatically in accumulation mode, while it increases slightly in nucleation mode. This is in accordance with the result of HC and soot emissions discussed above. The particles in nucleation mode normally consist of soluble organic fraction (SOF) and sulfate. At high injection pressures, lots of incomplete combustion and quenching lead to high HC emission and organics formation. Therefore there are a lot of particles in nucleation mode. It is well known that the main part of the particles in accumulation mode is dry soot. At low injection pressure, it is difficult for the fuel to be atomized and produce much soot emission. So there are many particles in accumulation mode. The particle number of the diesel is higher than that of the gasoline-type fuels and the average size of diesel is smaller.



(a) (b)

Fig. 3. (a) soot emission; (b) particle number

3.4. Thermal efficiency

The indicated thermal efficiency of gasoline-type fuels increases at high injection pressure attributed by higher combustion stability and better combustion phase which is closer to TDC (Fig. 4). Even though diesel has higher combustion efficiency at high injection pressure, it has lower thermal efficiency than gasoline-like fuels which have low heat transfer and exhaust loss due to the early combustion phase.

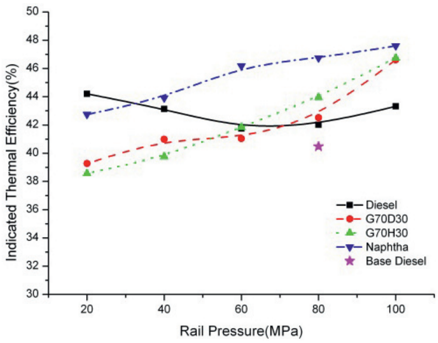


Fig. 4. Indicated thermal efficiency

4. Conclusions

(1) With the rise of injection pressure, the combustion delay is extended for gasoline-type fuels, while it is shortened for diesel. Naphtha has the longest combustion delay. The MPRR of diesel is much higher than that of gasoline-type fuels. The indicated thermal efficiency is higher for gasoline-type fuels at high injection pressure.

(2) The emissions of CO and HC of gasoline fuels increase with the rise of injection pressure, while the emission of NO_x is high at the very low (20MPa) or very high (100MPa) injection pressure. Heavy naphtha has the highest CO and HC emissions but the lowest NO_x emission. Diesel has the lowest CO and HC emissions but the highest NO_x emission.

(3) The soot emission decreases significantly with the increase of injection pressure. When the injection pressure increases, the particle number of gasoline-type fuels decreases in accumulation mode but increases in nucleation mode. Diesel has the highest soot and particle number emissions.

Acknowledgements

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Biography

Dr. Shijin Shuai is a professor in the State Key Laboratory of Automotive Safety and Energy, Tsinghua University, China. He has 20+ years' fundamental research and development experience ranging from gasoline compression ignition (GCI) combustion, emission control and alternative fuels with 100+ technical papers published in journals and international conferences.